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A Procedure for Accurately Measuring the Shaker Overturning Moment during Random Vibration Tests

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Introduction

Motivation:

- For large system level random vibration tests, there may be some concerns about the shaker's capability for the overturning moment.
- It is the test conductor's responsibility to predict and monitor the overturning moment during random vibration tests.
- If the predicted moment is close to the shaker's capability, test conductor must measure the instantaneous moment at low levels and extrapolate to higher levels. That data will be used to decide whether it is safe to proceed to the next test level.

Challenge:

- Kistler analog formulation for computing the real-time moment is only applicable to very limited cases in which we have 3 or 4 load cells installed at shaker interface with hardware.

Approach:

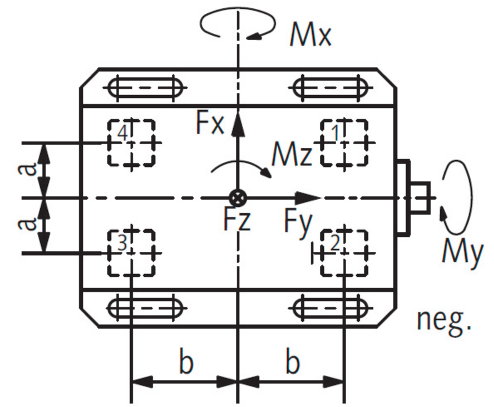
- To overcome that limitation, a simple procedure was developed for computing the overturning moment time histories using the measured time histories of the individual load cells.

Overturning Moment Measurement using Kistler Charge Amps

- Kistler 8-channel charge amps (type 5017B or 5080A) are capable of measuring the summed forces as well as the resulting moment.
- However, the Kistler approach to use analog signals for computing the overturning moment is ***only applicable if there are three or four load cells*** installed at the interface with the shaker head.
- If there are many load cells at the interface, to implement the Kistler method, one need to group them into 3 or 4 groups, and that can cause a significant error in measuring the moment, since it ignores the amplitude and phase differences within a group.
- Moreover, this approach ignores the shear force contribution and static force contribution to moment.

Kistler Type 5080A

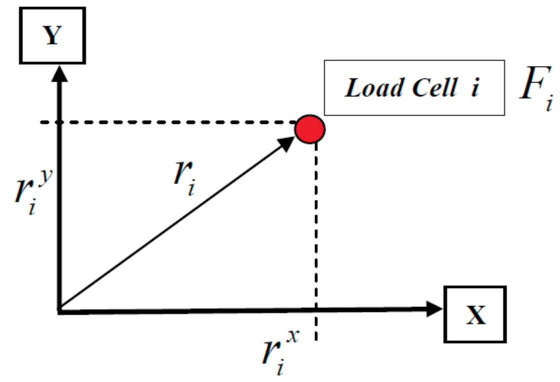
6-Component Force and Torque Measurement Fx, Fy, Fz, Mx, My, Mz with 8-Channel Charge Amplifier



Formulae for Calculations

$$F_x = F_{x1+2} + F_{x3+4}$$
$$F_y = F_{y1+4} + F_{y2+3}$$
$$F_z = F_{z1} + F_{z2} + F_{z3} + F_{z4}$$
$$M_x = [b \cdot (F_{z1} + F_{z2} - F_{z3} - F_{z4})]\ kM_x$$
$$M_y = [a \cdot (-F_{z1} + F_{z2} + F_{z3} - F_{z4})]\ kM_y$$
$$M_z = [b \cdot (-F_{x1+2} + F_{x3+4}) + a \cdot (F_{y1+4} - F_{y2+3})]\ kM_z$$

A Procedure for Measuring the Overturning Moment Time History (1/2)



- Suppose N load cells measuring the interface load between the shaker head and the hardware
- For each load cell '*i*', its location with respect to the shaker centerline can be described using a vector r_i in the XY plane
- The overturning moment has three parts:

1) Contribution of the Vertical Forces:

$$\begin{Bmatrix} \mathbf{M}_X^I(t) = \sum_{i=1}^{N} r_i^y f_i^z(t) \\ \mathbf{M}_Y^I(t) = -\sum_{i=1}^{N} r_i^x f_i^z(t) \end{Bmatrix}$$

2) Contribution of the Shear Forces:

$$\begin{Bmatrix} \mathbf{M}_X^{II}(t) = -\Delta Z \sum_{i=1}^{N} f_i^y(t) \\ \mathbf{M}_Y^{II}(t) = \Delta Z \sum_{i=1}^{N} f_i^x(t) \end{Bmatrix}$$

Where ΔZ is the vertical distance between the shaker head and the load cell locations

3) Contribution of the Weight and Center of Mass (CM) offset (Static):

Since the load cell's charge amplifiers are set to zero-out the DC load due to the weight, we need to manually add the static overturning moment

$$\begin{Bmatrix} \mathbf{M}_X^{III}(t) = -\Delta Y \; mg \\ \mathbf{M}_Y^{III}(t) = \Delta X \; mg \end{Bmatrix}$$

where the ΔX and ΔY are the test article's CM offset relative to the shaker centerline in the X and Y directions, respectively

A Procedure for Measuring the Overturning Moment Time History (2/2)

- So the total moment about the X and Y directions can be calculated by summing the three components as follows:

$$Total\ \ Moment \begin{cases} M_X(t) = \sum_{i=1}^{N} \left(r_i^y f_i^z(t) \right) - \Delta z \cdot \sum_{i=1}^{N} f_i^y(t) - \Delta y\ mg \\ M_Y(t) = -\sum_{i=1}^{N} \left(r_i^x f_i^z(t) \right) + \Delta z \cdot \sum_{i=1}^{N} f_i^x(t) + \Delta x\ mg \end{cases}$$

- To check against the rated capability, we need to compute the instantaneous magnitude as follows:

$$Moment\ \ Magnitude = \left| \mathbf{M}(t) \right| = \sqrt{M_X^2(t) + M_Y^2(t)}$$

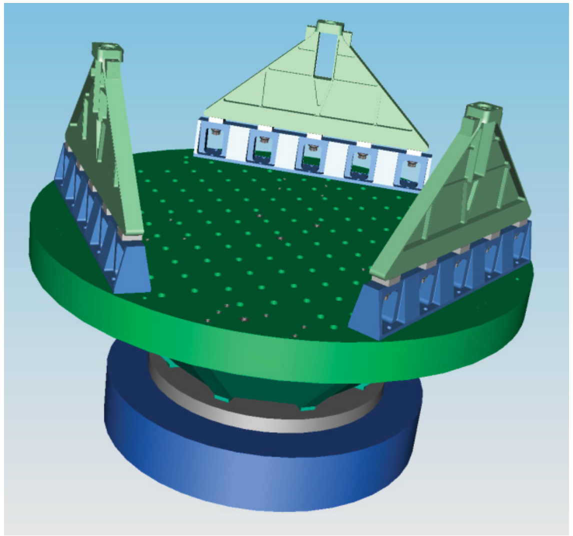
- **Notes:**

1) The total moment is computed instantaneously for each time step t. Consequently, the phasing information is preserved.

2) Since three moment parts are added to get the total moment, we need to be consistent about the signs.

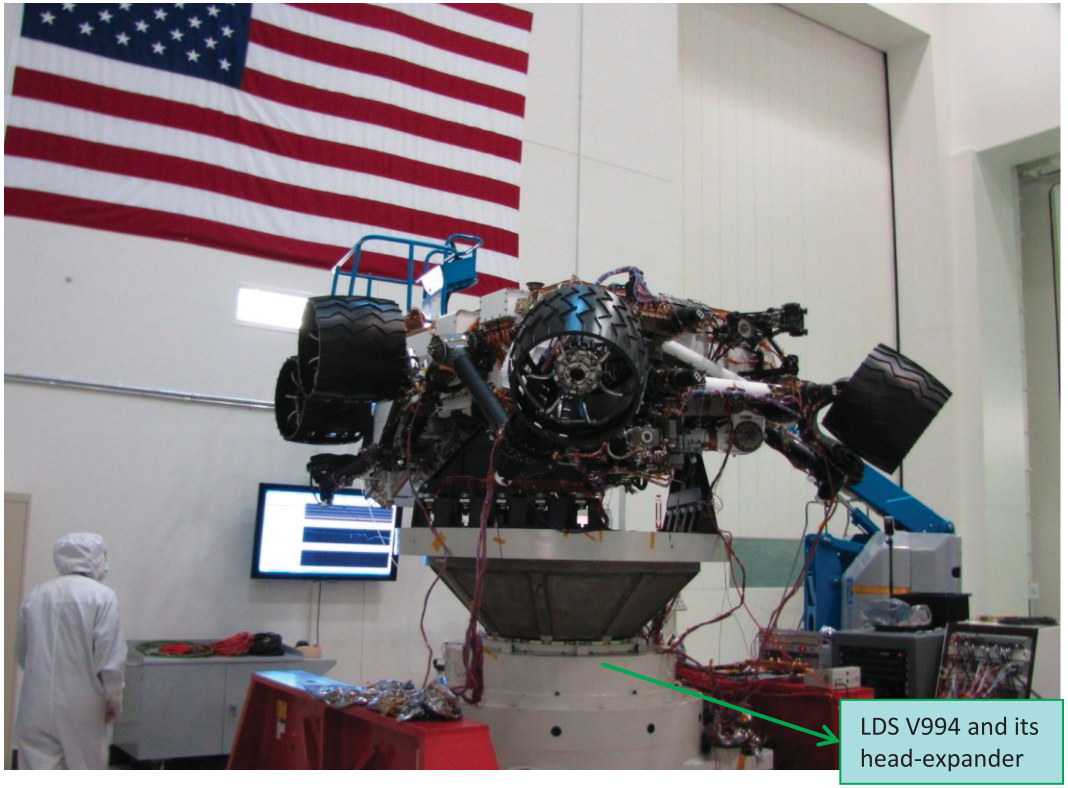
3) The static moment contribution depends ***only*** on the mass and CM offset, and is constant throughout the test runs. So that part should not be scaled, when we scale the low level runs to project to a higher level run

Overturning Moment Measurements for the MSL Rover Protoflight Random Vibration Tests (1/2)



15 load cells positioned in a triangle configuration as shown (5 per side)

Load Cell No	X[in]	Y [in]	Z [in]	CH No.
Fz 1	-25.0	15.1	25.4	1
Fz 2	-25.0	7.6	25.4	2
Fz 3+4	-25.0	-3.8	25.4	3
Fz 5	-25.0	-15.1	25.4	4
Fz 6	-0.6	-29.2	25.4	5
Fz 7	5.9	-25.4	25.4	6
Fz 8+9	15.8	-19.8	25.4	7
Fz 10	25.6	-14.1	25.4	8
Fz 11	25.6	14.1	25.4	9
Fz 12	15.8	19.8	25.4	10
Fz 13+14	5.9	25.4	25.4	11
Fz 15	-0.6	29.2	25.4	12
Sum Fx	-	-	-	13
Sum Fy	-	-	-	14



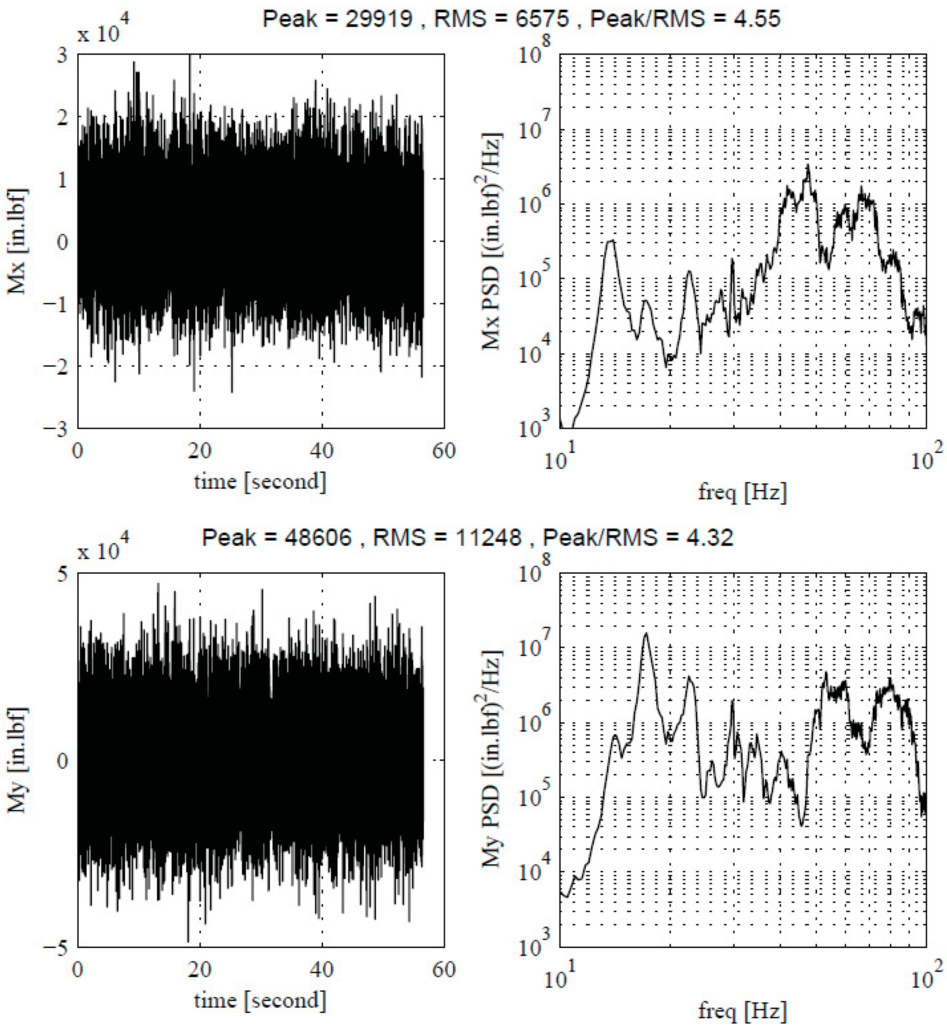
Mass = 2115 [lbm]
CM offset: ΔX= 0.25, ΔY= -0.80 [in]

Number of Load Cells: 15

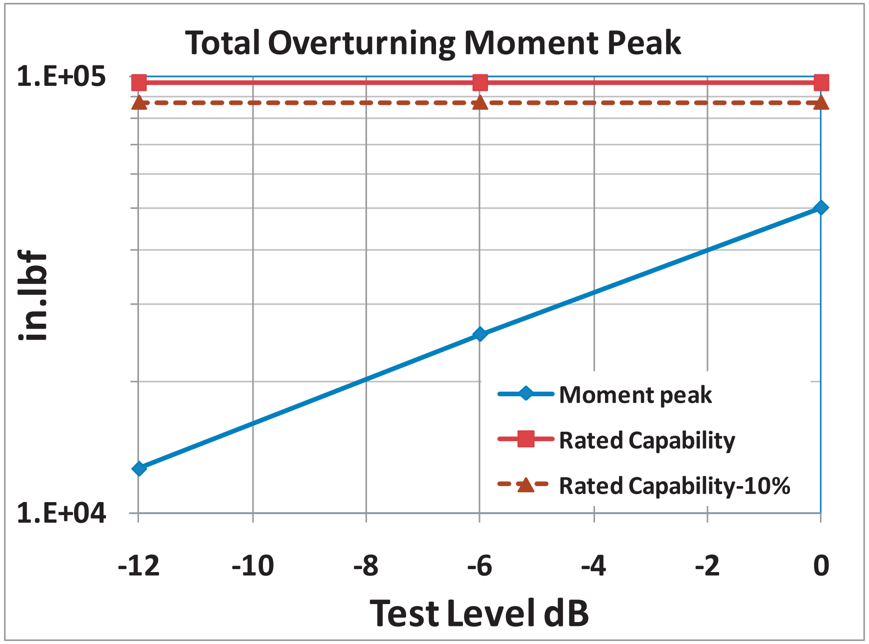
The vertical distance between the shaker head and the load cell locations: ΔZ = 25.4 [in]

Overturning Moment Measurements for the MSL Rover Protoflight Random Vibration Tests (2/2)

Moment Time Histories & PSD for the Full level Run

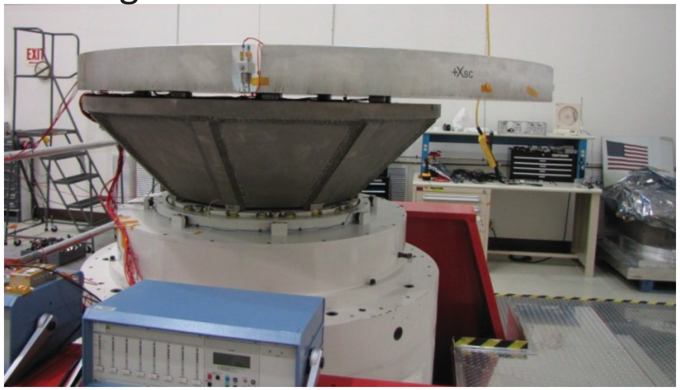


Peak Moment versus test level

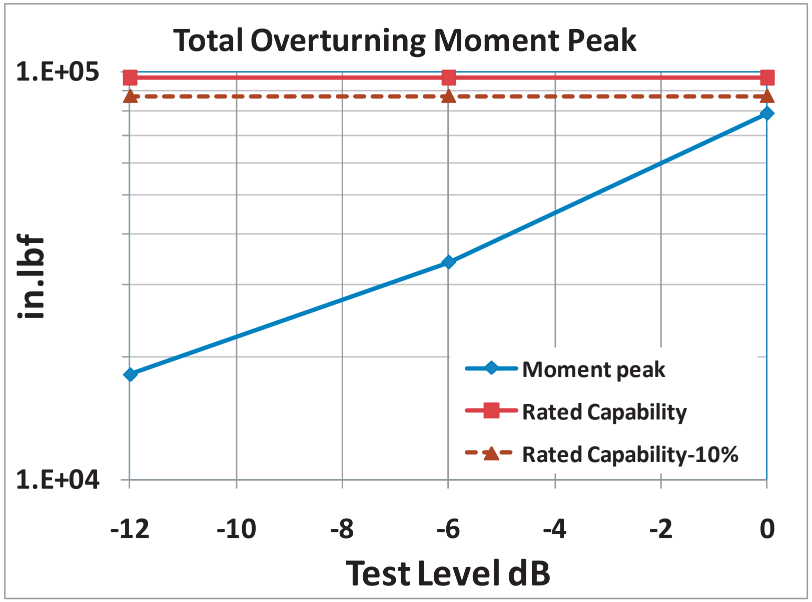


MSL Descent-Stage PF Random Vibration Tests

overturning moment proof test
using a mass model with CM offset



Peak Moment versus test level



Summary

- For large system level random vibration tests, when the overturning moment prediction from FEM is high enough to raise concern, the test conductor must measure and monitor the moment during the low level runs to decide whether it is safe to proceed to the next test level.

- Kistler approach is not accurate enough since:
  - it ignores the amplitude and phase differences within a group
  - it ignores the shear force contribution
  - it ignores the static force contribution

- The procedure described in this article, is simple to implement and is capable of accurately measuring the overturning moment time histories using the measured time histories of the individual load cells.